DØ Note 4481-CONF

# Reconstruction of $B$ hadron signals at DØ

The DØ Collaboration
*URL http://www-d0.fnal.gov*
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In this note, we present details on the reconstruction of $B$ hadrons into final states containing a $J/\psi$ and also semi-leptonic decays. The data used here was collected between April 2002 and January 2004 and corresponds to about 250 $\mathrm{pb}^{-1}$.

*Preliminary Results for Conferences*

## I. INTRODUCTION

We have reconstructed large samples of exclusive B-hadron decays into final states containing a $J/\psi$, *e.g.*, $B^{\pm} \to J/\psi K^{\pm}$, and also semi-leptonic decays. This note describes the selection criteria used for the various modes.

We first describe the final states containing a $J/\psi$ and then the semi-leptonic modes.

## II. DATA SAMPLE

The data sample used in the reconstructed mass peaks in this note is a skim [1] from the Common Sample Group. This "D" skim, was produced for $B$ analyses in semileptonic decays including a $D$ meson, and for other decay modes including dimuons in the decay channel with a $J/\psi$ decaying to muons. The data used here was collected between April 2002 and January 2004, and corresponds to about 250 pb$^{-1}$.

## III. FINAL STATES WITH A $J/\psi$

$J/\psi$'s are reconstructed via the $\mu^+\mu^-$ decay mode. These events are mainly collected by the dimuon triggers. DØ has a variety of dimuon triggers, some requiring muons to have hits in at least two of the three layers (of the muon system), and others which allow for one or both muons to have hits only in the innermost muon layer. The former category of triggers are unprescaled, whereas the latter class are generally prescaled. Due to trigger inefficiences, some decays are also collected by the inclusive single muon triggers (which have luminosity dependent prescales).

We consider all events which have at least two well identified muons. Muons are identified by extrapolating tracks (identified in the central tracking system) and matching them with muon track segments formed from hits in the muon system. Figure 1 shows the invariant mass for oppositely-charged for 240 pb$^{-1}$ of data satisfying the specific dimuon triggers `mu2ptxatxx`, `2MU_A_L2ETAPHI`, `MU2_A_L2MO`, and `MU2_A_L3_L0` for muons satisfying a loose requirement. The requirements for the dimuon skim (CS filter "SKIM_AA_JPSI") are as follows:

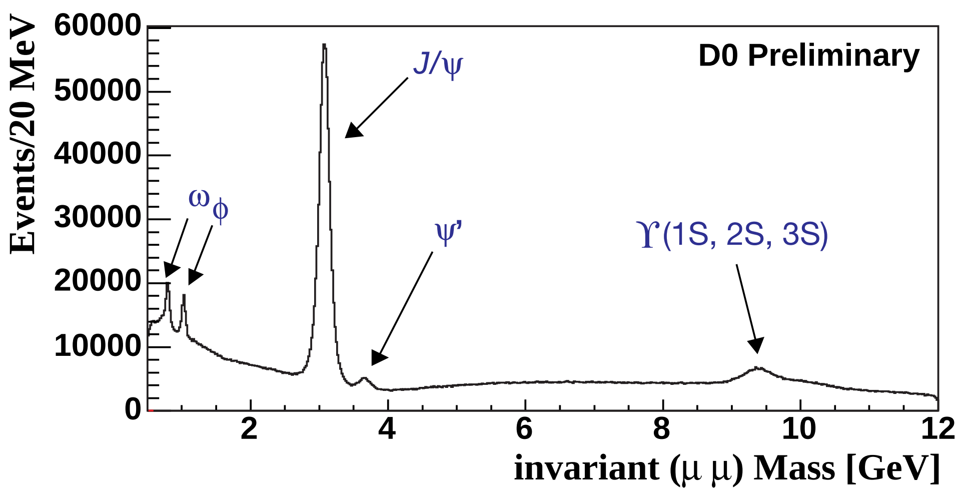


FIG. 1: Invariant mass of $\mu^+\mu^-$ combinations for specific dimuon triggers (see text).

- two loose certified muons of opposite charge;
- if $nseg > 0$, then $p_T > 1.5$ GeV/$c$ (i.e., allow $p_T < 1.5$ GeV/$c$ only for $nseg = 0$ muons);
- $p_T > 1.0$ GeV/$c$ for each particle;
- number of CFT hits $> 1$ for each particle;
- at least 1 muon with $nseg = 3$;
- for muons with $nseg = 0$:

- $p_T(\mu^+\mu^-) > 4.0$ GeV/$c$;
- $nmtc() \geq 0$;
- $CalEsig() > 0.015 \cdot CalNLayer()$;
- $p < 7$ GeV/$c$;
- $p_T > 2.5$ GeV/$c$ for the second muon;
- $\chi^2 < 25$ for the global muon fit for both particles.

- $M(\mu^+\mu^-) > 2.5$ GeV/$c^2$.

Tracks are clustered into jets using the Durham algorithm [2].

The primary vertex was found in each event using the method described in Ref. [3]. The crossing point of the two beams, i.e., the beamspot (as given in AATrack/dat/beamSpot-2.09), was used as a constraint in the primary vertex fit.

### A. $J/\psi$ reconstruction

Oppositely charged muons are combined to form $J/\psi$ candidates. We consider only those candidates whose mass is between 2.8 and 3.35 GeV/$c^2$. Figure 2 shows the resulting $\mu^+\mu^-$ mass spectrum.

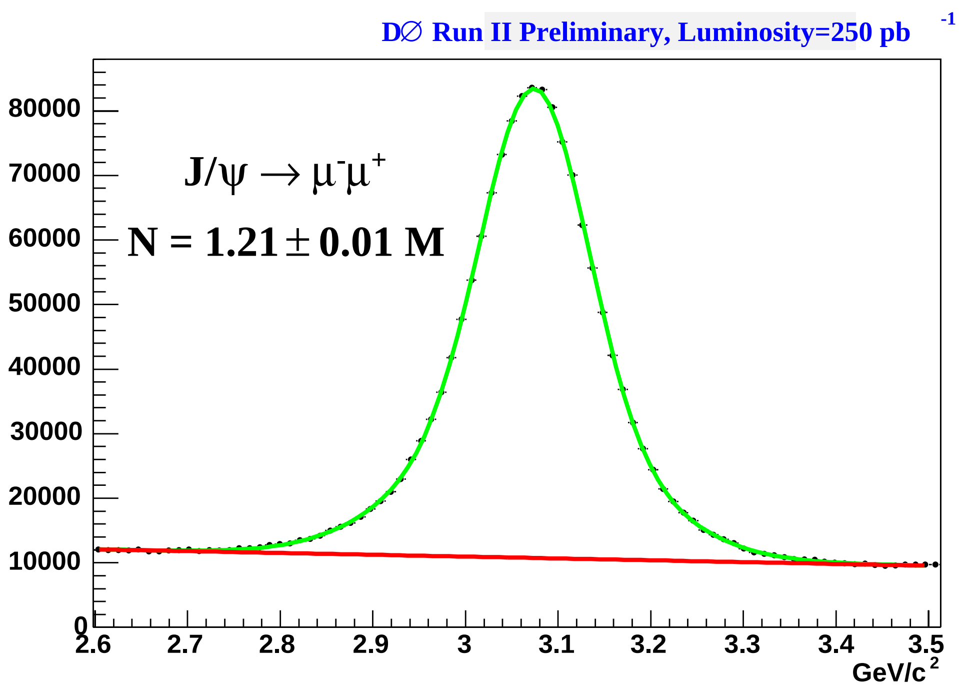


FIG. 2: Mass of $\mu^+\mu^-$ candidates.

### B. $B^+ \to J/\psi K^+$ reconstruction

To reconstruct the $B^+$, we first apply the following selection criteria on the kaon. The kaon track has to have at least two hits in the silicon detector, and cannot have more than two misses (beyond the last measured point) in the central tracker. We reject tracks if they can be identified as daughters of the decays $K_S^0 \to \pi^+\pi^-$, $\Lambda \to p\pi^-$ and $\gamma \to e^+e^-$. In addition, we require $p_T(K^+) > 0.5$ GeV/$c$, and $p_{tot} > 0.7$ GeV/$c$. If $p_T(K^+) < 1.0$ GeV/$c$, it is required to be in the same jet as the $J/\psi$. To enhance the $B$ signal, the (3-D) impact parameter significance of the kaon, relative to the primary vertex, has to be greater than 3. It is also required that $p_T(J/\psi) > 5$ GeV/$c$, and the candidate mass is constrained to its nominal value.

We require the $B^+$ candidate to satisfy additional selection criteria. At least two of the three tracks should have at least two hits in the silicon detector. The $\chi^2$ of the three track vertex should be less than 16 (for 3 d.o.f) – for $p_T(K^+) < 1.0$ GeV/$c$, this is tightened to 9. To reduce combinatoric background, the decay length significance, $L/\sigma_L$, of the $B^+$ candidate should be greater than 4.5 (increased to 5.5, if $p_T(K^+) < 1.0$ GeV/$c$), and $\cos(\alpha) > 0.9$, where $\alpha$ is the angle between $B^+$ momentum and the direction from primary to the $B^+$ vertex.

The resulting signal is presented in Fig. 3.

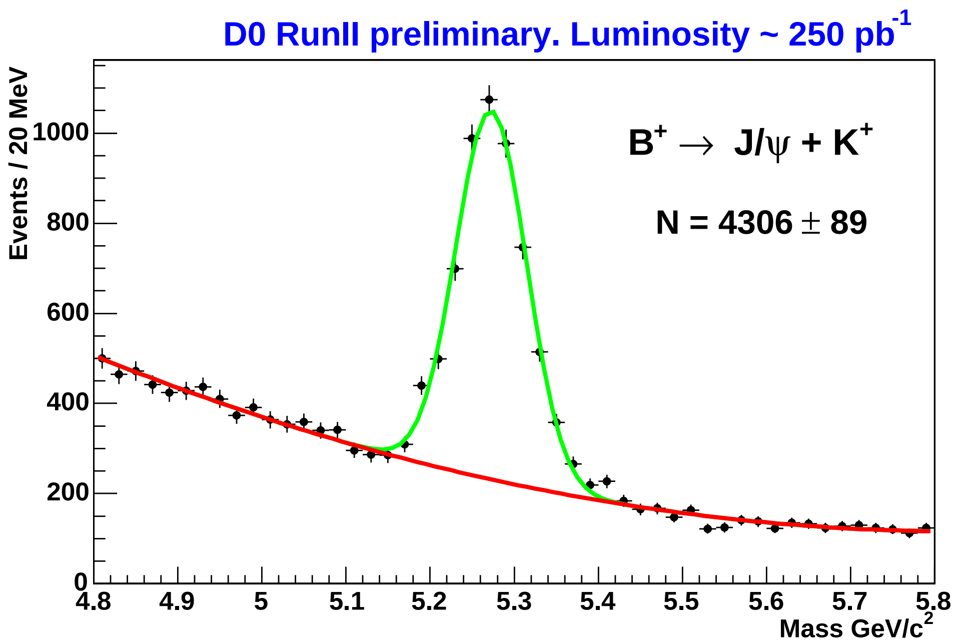


FIG. 3: Mass of $\mu^+\mu^-K^\pm$ candidates.

### C. $B_d^0 \to J/\psi K^{*0}$ reconstruction

The $K^{*0}$ is detected in the $K^+\pi^-$ mode. We consider all tracks with $p_T > 0.3$ GeV/$c$, and require that each track have at least two hits in the Silicon tracker. If either of the kaon or pion track has $p_T < 0.7$ GeV/$c$, then both tracks have to be in the same jet as the $J/\psi$. We take all two track combinations with mass between 0.770 and 0.930 GeV/$c^2$ – if both combinations fall in this window, we take the one with mass closer to the nominal $K^*$ mass. The $J/\psi$ candidate's mass is constrained to its nominal mass. The resulting signal is shown in Fig. 4 for $K^{*0}$ candidates that when combined with $J/\psi$, result in a $B_d^0$ mass between 5.2 and 5.4 GeV/$c^2$.

We require the $B^0$ candidate to satisfy additional selection criteria. At least two of the four tracks should have at least one hit in the silicon detector. The $\chi^2$ of the four track vertex should be less than 32 (for 5 d.o.f) – for $p_T(K/\pi) < 1.0$ GeV/$c$, this is tightened to 9.

To reduce combinatoric background, the decay length significance of the $B^0$ candidate should be greater than 2.0 (increased to 4.5, if $p_T(K/\pi) < 1.0$ GeV/$c$), and $\cos(\alpha) > 0.97$, where $\alpha$ is the angle between $B^0$ momentum and the direction from primary to the $B^0$ vertex (normally, we require this to 0.95).

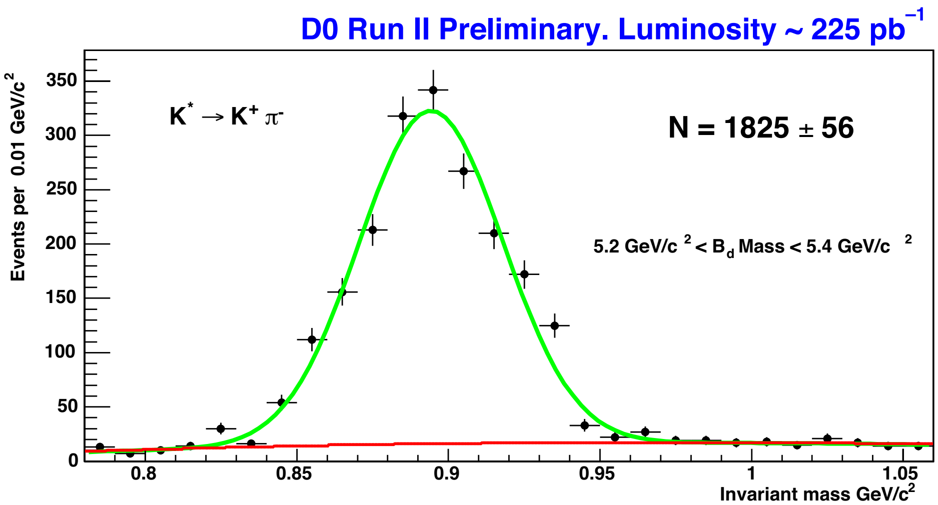


FIG. 4: Mass of $K^{*0} \to K^+\pi^-$ candidates that have been combined with a $J/\psi$ and fall within the indicated $B_d^0$ mass window.

The resulting signal is presented in Fig. 5.

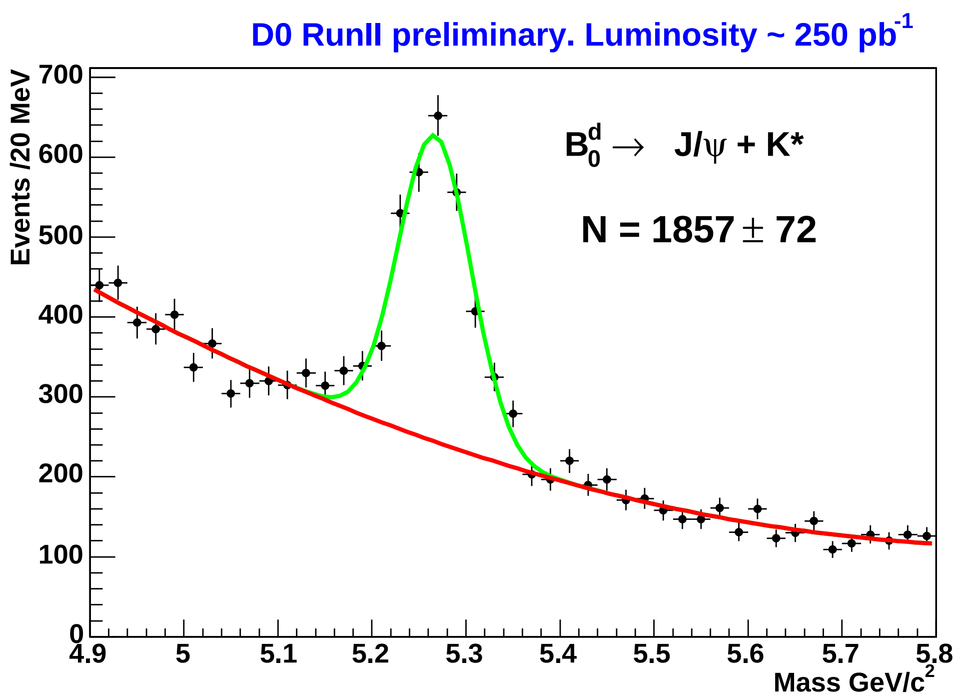


FIG. 5: Mass of $\mu^+\mu^-K^{*0}$ candidates.

### D. $B_d^0 \to J/\psi K_S^0$ reconstruction

The $K_S^0$ is detected in the $\pi^+\pi^-$ mode. We consider all tracks, and require that each track have at least two hits in the Silicon tracker. We take all two track combinations with mass between 0.460 and 0.525 GeV/$c^2$ and $p_T > 0.4$ GeV/$c$. To reduce background from $K_S^0$ produced during fragmentation, their decay length significance is required to be greater than 3.0. Both $J/\psi$ and $K_S^0$ candidates are constrained to their nominal mass.

We require the $B^0$ candidate to satisfy additional selection criteria. At least two of the four tracks should have at least two hits in the silicon detector. The $\chi^2$ of the $B$ vertex should be less than 25 (for 5 d.o.f).

To reduce combinatoric background, the decay length significance of the $B^0$ candidate should be greater than 3.0, and $cos(\alpha) > 0.9$, where $\alpha$ is the angle between $B^0$ momentum and the direction from primary to the $B^0$ vertex. The $B^0$ candidate is required to have $p_T > 5$ GeV/$c$.

The resulting signal is presented in Fig. 6.

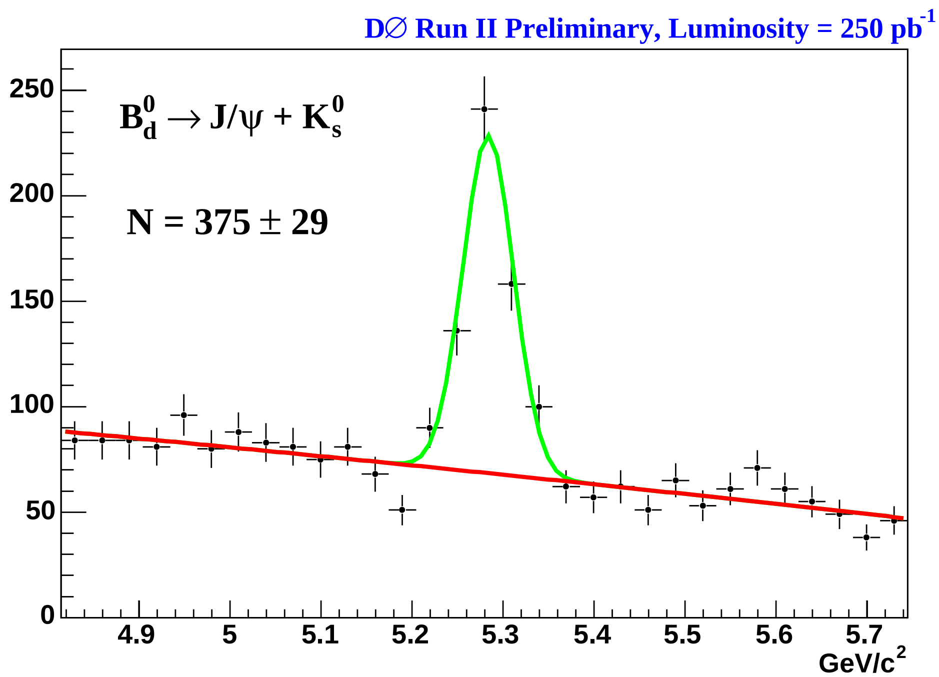


FIG. 6: Mass of $\mu^+\mu^- K_S^0$ candidates.

### E. $B_s^0 \to J/\psi\phi$ reconstruction

The $\phi$ is detected in the $K^+K^-$ mode. We consider all tracks with $p_T > 0.4$ GeV/$c$, and require that each track have at least two hits in the Silicon tracker. If either of the kaons has $p_T < 0.7$ GeV/$c$, we require its impact parameter significance relative to the primary vertex to be greater than 1.0 and $p_T(\phi) > 0.8$ GeV/$c$. We take all two track combinations with $1.01 < M(K^+K^-) < 1.032$ GeV/$c^2$. It is also required that $p_T(J/\psi) > 3$ GeV/$c$ and the candidate mass is constrained to its nominal value. The resulting signal is shown in Fig. 7 for $\phi \to K^+K^-$ candidates that when combined with $J/\psi$, result in a $B_s^0$ mass between 5.28 and 5.46 GeV/$c^2$.

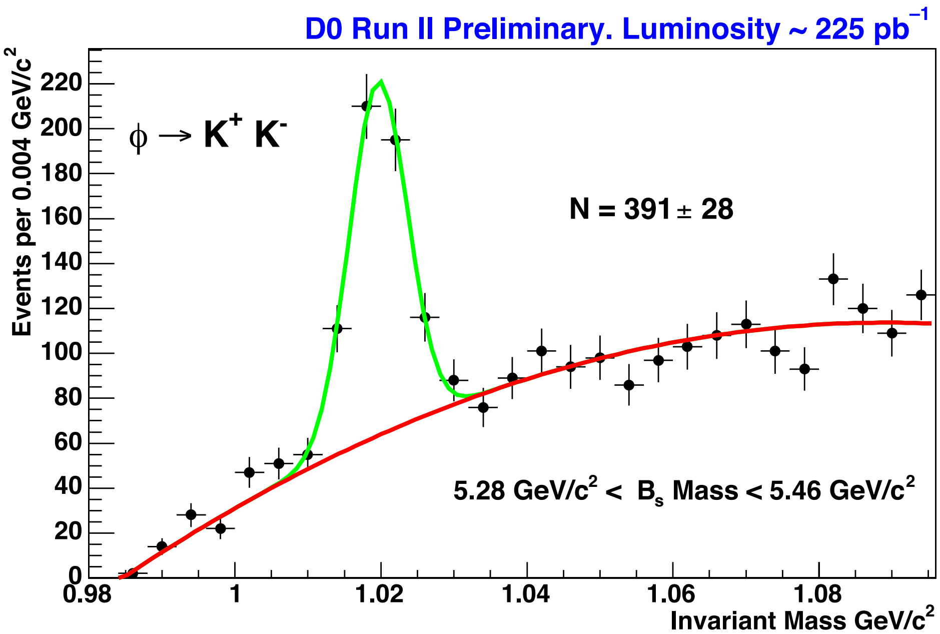


FIG. 7: Mass of $\phi \to K^+K^-$ candidates that have been combined with a $J/\psi$ and fall within the indicated $B_s^0$ mass window.

We require the $B_s$ candidate to satisfy additional selection criteria. At least two of the four tracks should have at least one hit in the silicon detector. The $\chi^2$ of the four track vertex should be less than 32 (for 5 d.o.f) – for $p_T(K) < 0.7$ GeV/$c$, this is tightened to 7.

To reduce combinatoric background, the decay length significance of the $B^0$ candidate should be greater than 3.0 (increased to 4.5 if $p_T(K) < 0.7$ GeV/$c$), and $\cos(\alpha) > 0.9$, where $\alpha$ is the angle between $B^0$ momentum and the direction from primary to the $B^0$ vertex.

The resulting signal is presented in Fig. 8.

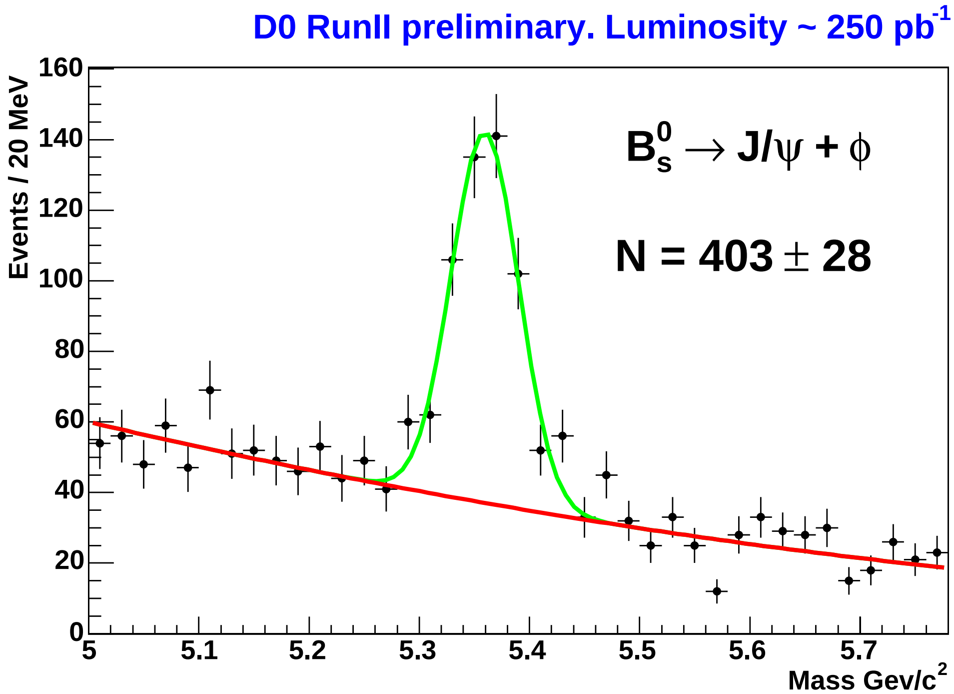


FIG. 8: Mass of $\mu^+\mu^-\phi$ candidates.

### F. $\Lambda_b \to J/\psi\Lambda$ reconstruction

The $\Lambda$ is detected in the $p\pi^-$ mode. We consider all tracks, and require that each track have at least two hits in the Silicon tracker. We take all two track combinations with mass between 1.105 and 1.125 GeV/$c^2$ and $p_T > 0.4$ GeV/$c$. To reduce background from $\Lambda$ produced during fragmentation, their decay length significance is required to be greater than 3.0. Both $J/\psi$ and $\Lambda$ candidates are constrained to their nominal mass.

We require the $\Lambda_b$ candidate to satisfy additional selection criteria. The $\chi^2$ of the $\Lambda_b$ vertex should be less than 25 (for 5 d.o.f). To reduce combinatoric background, the decay length significance of the $\Lambda_b$ candidate should be greater than 3.0, and $\cos(\alpha) > 0.9$, where $\alpha$ is the angle between $\Lambda_b$ momentum and the direction from primary to the $\Lambda_b$ vertex. It is required that the $\Lambda_b$ candidate's total $p > 5$ GeV/$c$.

The resulting signal is presented in Fig. 9.

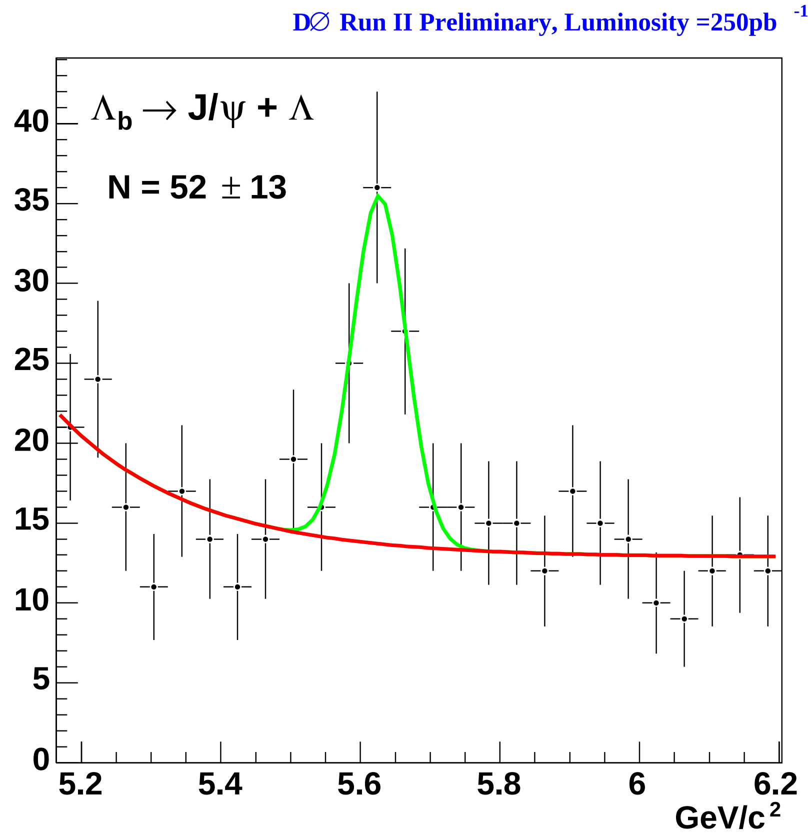


FIG. 9: Mass of $\mu^+\mu^-\Lambda$ candidates.

## IV. SEMI-LEPTONIC FINAL STATES

Currently we only use the semi-muonic final state. Most of these events are collected on the inclusive single muon trigger. For these modes, the pseudo-rapidity $|\eta^\mu| < 2$, $p_T(\mu) > 2.0$ GeV/$c$, and the $p(\mu) > 3$ GeV/$c$. Certified muons are used as before, with $\chi^2$ of the local muon fit required to be positive, the number of SMT and CFT hits greater than 1 in each case, and $nseg > 1$.

All charged particles in event were clustered into jets using the DURHAM clustering algorithm [2] with the $P_t$ cut-off parameter 15 GeV/c [4]. Events with more than one identified muon in the same jet were rejected, as well as the events with identified $J/\psi \to \mu^+\mu^-$ decay.

### A. $B \to D^0\mu X$ reconstruction

The $\bar{\mathrm{D}}^0$ candidate was constructed from 2 particles of opposite charge included in the same jet as the reconstructed muon. Both particles should have hits in SMT and CFT, the transverse momentum $p_T > 0.7$ GeV/c and the pseudo-rapidity $|\eta| < 2$. They should have the common $D$-vertex with the $\chi^2_D < 9$ of vertex fit. For each particle, the axial [5] $\epsilon_T$ and stereo [6] $\epsilon_L$ projections of track impact parameter with respect to the primary vertex together with the corresponding errors ($\sigma(\epsilon_T)$, $\sigma(\epsilon_L)$) were computed. The combined significance $(\epsilon_T/\sigma(\epsilon_T))^2 + (\epsilon_L/\sigma(\epsilon_L))^2$ was required to be greater than 4. The distance $d_T^D$ between the primary and $D$ vertices in the axial plane was required to exceed 4 standard deviations: $d_T^D/\sigma(d_T^D) > 4$. The angle $\alpha_T^D$ between the $\bar{\mathrm{D}}^0$ momentum and the direction from the primary to $\bar{\mathrm{D}}^0$ vertex in the axial plane should satisfy the condition: $\cos(\alpha_T^D) > 0.9$.

The tracks of muon and $\bar{\mathrm{D}}^0$ candidate should produce the common $B$-vertex with the $\chi^2_B < 9$ of vertex fit. The momentum of $B$ candidate was computed as the sum of momenta of $\mu$ and $\bar{\mathrm{D}}^0$. The mass of $(\mu^+\bar{\mathrm{D}}^0)$ system should be within the limits: $2.3 < M(\mu^+\bar{\mathrm{D}}^0) < 5.2$ GeV/c$^2$. If the distance $d_T^B$ between the primary and $B$ vertices in the axial plane exceeded $4 \cdot \sigma(d_T^B)$, the angle $\alpha_T^B$ between the $B$ momentum and the direction from primary to $B$ vertex in the axial plane should satisfy the condition: $\cos(\alpha_T^B) > 0.95$. The distance $d_T^B$ was allowed to be greater than $d_T^D$, provided that the distance between B and D vertices $d_T^{BD}$ was less than $3 \cdot \sigma(d_T^{BD})$.

The mass spectrum of $(K\pi)$ system after all these selections is shown in Fig.10. The masses of kaon and pion were assigned to particles according to the charge of the muon, requiring $\mu^+ K^+ \pi^-$ final system. The mass spectrum with the opposite mass assignment $\mu^+ K^- \pi^+$, also shown in Fig.10, does not give any mass structure, which confirms the correlated production of $\mu^+ \bar{D}^0$ system, as it is expected in $B$ decay. The signal in the $\bar{D}^0$ peak contains $\sim 109000$ events.

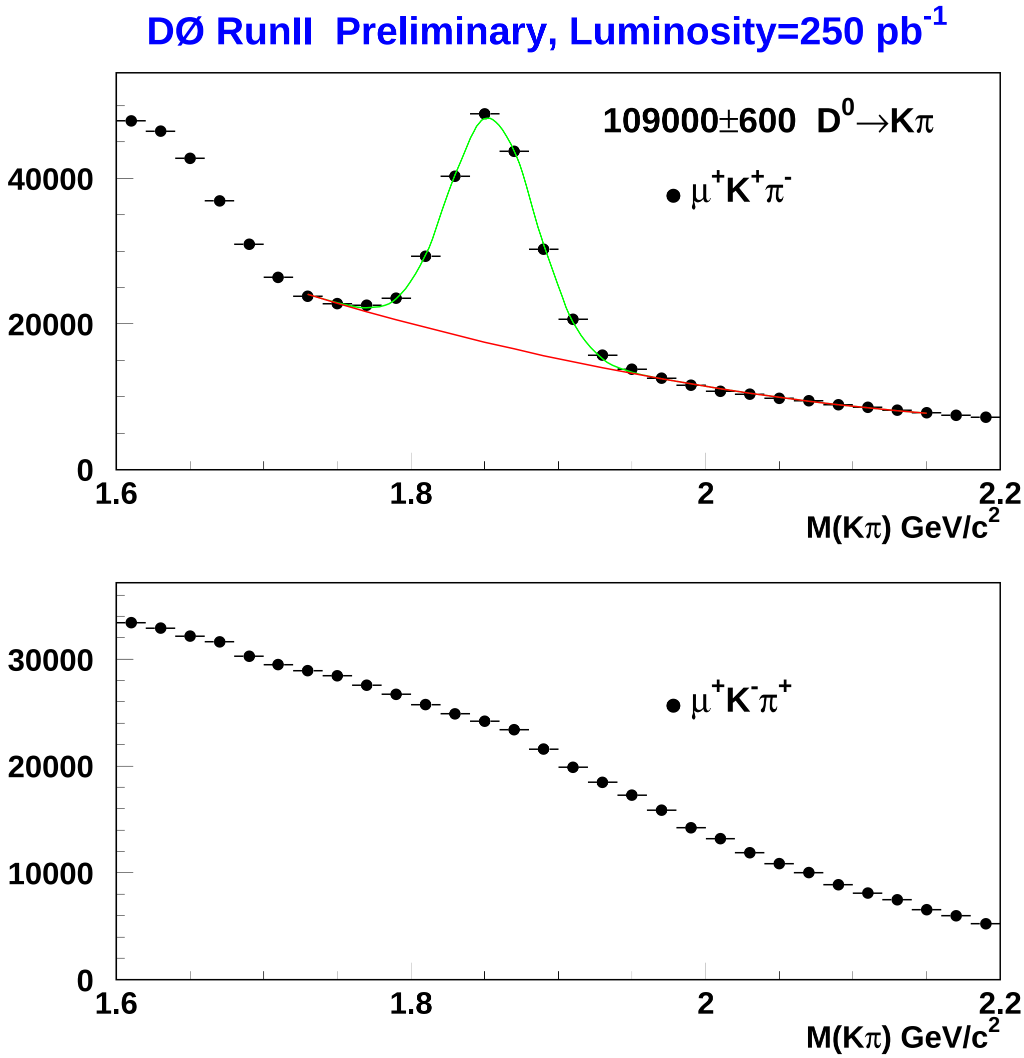


FIG. 10: The invariant mass of $K\pi$ system for $\mu^+ K^+ \pi^-$ (points with errors) and $\mu^+ K^- \pi^+$ (filled histogram) mass assignment. The curve shows the result of the fit of the $K^+ \pi^-$ mass distribution with Gaussian and polynomial background. Points in the left peak, corresponding to partially reconstructed decay $\bar{D} \to K^+ \pi^- X$, were assigned a zero weight in this fit.

### B. $B \to D^{*+}\mu X$ reconstruction

For each $\mu^+\bar{\mathrm{D}}^0$ candidate, the additional pion with the charge opposite to the charge of muon was searched for. The mass difference $\Delta M = M(\bar{\mathrm{D}}^0\pi) - M(\bar{\mathrm{D}}^0)$ for all such pions, when $1.80 < M(\bar{\mathrm{D}}^0) < 1.9$ GeV/c$^2$, is shown in Fig.11. The peak, corresponding to the production of $\mu^+\mathrm{D}^{*-}$ system is clearly seen.

The events containing a pion with the same charge as the muon give an estimate of the combinatorial background in the D$^*$ sample. The $\Delta M$ distribution for such events is shown in Fig.11 as the filled histogram.

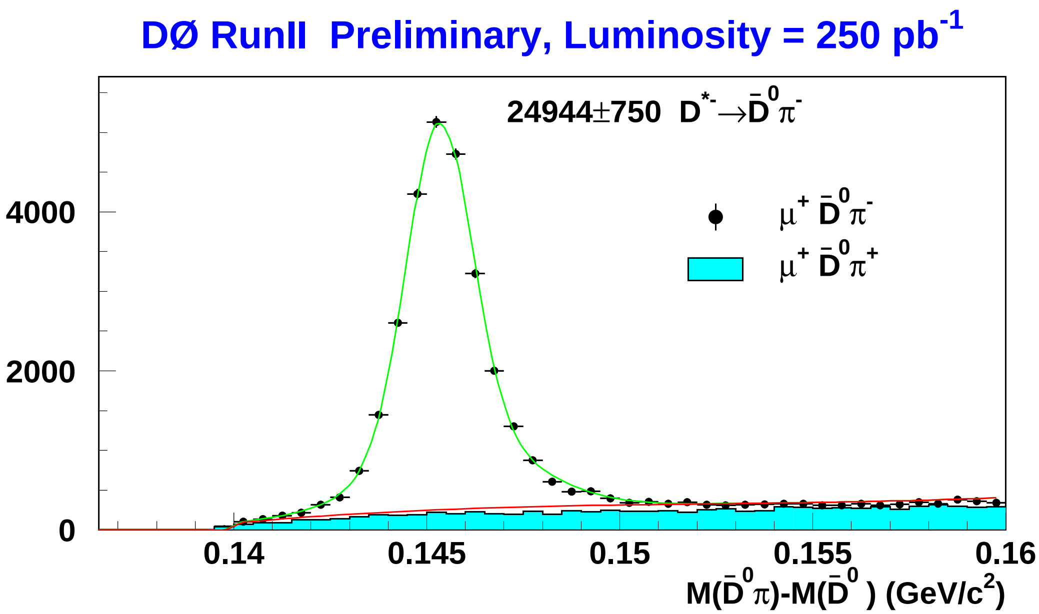


FIG. 11: The mass difference $M(\bar{D}^0\pi) - M(\bar{D}^0)$ for events with $1.80 < M(\bar{D}^0) < 1.9$ GeV/$c^2$ and an associated muon.

### C. $B \to D_s^+ \mu X$ reconstruction

The $D_s^+$ is detected in the $\phi\pi^+$ final state ($\phi \to K^+K^-$). All tracks have to be in the same jet and have $p_T > 0.7$ GeV/$c$. For the $\phi$ candidate, it is required that $1.008 < M(K^+K^-) < 1.028$ GeV/$c^2$, and for the $D_s$ candidate, $M(K^+K^-\pi) < 2.3$ GeV/$c^2$. To reduce combinatorics, the impact parameter significance of the pion and one of the kaons has to be $> 2$, and the (axial) decay length significance of the $D_s^+$ candidate (as measured from the primary vertex) has to be greater than 5.0. In addition, $\cos(\alpha) > 0.90$, where $\alpha$ is the angle between $D_s^+$ momentum and the direction from primary to the $D_s^+$ vertex.

The $\chi^2$ of the $\mu D_s^+$ vertex should be less than 16 (for 1 d.o.f.), and the mass of $\mu D_s^+$ is between 2.6 and 5.4 GeV/c$^2$. In addition, the charge of the muon has to be correlated with that of the pion ($Q_\mu * Q_\pi < 0$). If the $\mu D_s^+$ vertex is after the $D_s^+$ vertex, then the signficance of the distance between the $B$ and $D_s$ vertices has to less than 2. We also require that the $p_T$ of the muon relative to the $D_s^+ > 0.7$ GeV/$c$, $p_T(D_s^+) > 2.5$ GeV/$c$ and total $p(\mu D_s^+) > 7$ GeV/$c$.

The resulting $D_s^+$ signal for about 250 pb$^{-1}$ of data is presented in Fig. 12.

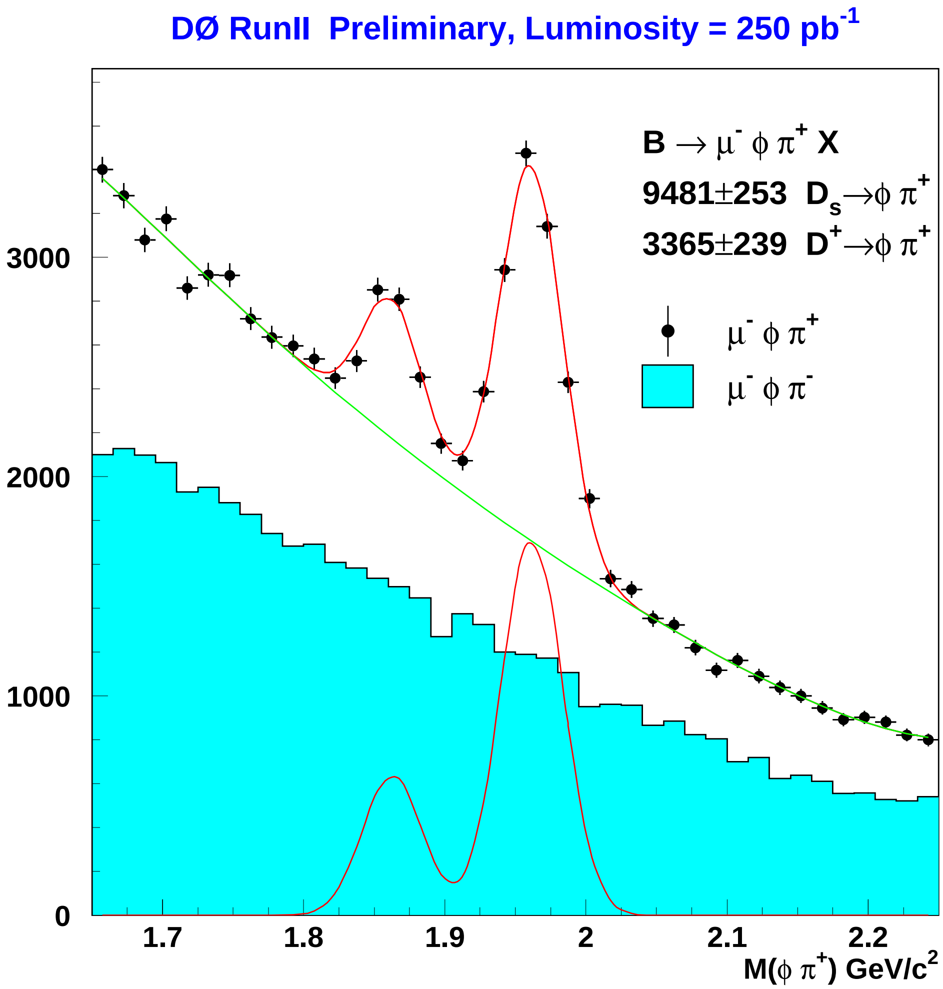


FIG. 12: Mass of $K^+K^-\pi^+$ candidates with an associated muon.

The blue histogram is the mass spectrum for the wrong sign $\mu D_s$ candidates.

[1] http://d0server1.fnal.gov/users/nomerot/Run2A/BANA/Dskim.html.
[2] S. Catani, Yu.L. Dokshitzer, M. Olsson, G. Turnock, B.R. Webber, *Phys Lett.* **B269** (1991) 432.

[3] DELPHI Collab., *Eur. Phys. J.* **C32** (2004) 185.
[4] T.Sjöstrand *et. al.*, hep-ph/0108264.
[5] Plane perpendicular to the beam direction.
[6] Parallel to the beam direction.